ALL YOU EVER WANTED TO KNOW BUT WERE AFRAID TO ASK ABOUT MEASUREMENT ANOMALIES IN BROADBAND AM-VSB SYSTEMS

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ABSTRACT

Currently, increasing numbers of cable operators are adopting fiber optic distribution systems using AM-VSB modulated signals. While this technology has been shown to be cost effective in various hybrid fiber/coax architectures, the sizable deployment now taking place represents significant capital expenditures. As a result, operators are embarking on perhaps the most intensive product evaluations and cost/performance trade-off reviews in the industry's history. However, there are several sources of measurement anomalies that must be taken into account to obtain meaningful and reproducible results as these systems are moved from the lab environment to the field.

This paper will focus on several sources of these anomalies such as spectrum analyzer frequency response, external bandpass filter tuning, software design utilized in automated testing, impedance matching of the system under test, etc. Also, several accuracy improvement techniques will be considered.

INTRODUCTION

The cable television technical community is well-versed in the art of making noise and distortion measurements in broadband AM-VSB modulated systems. It has available to it such guidelines as the "NCTA Recommended Practices for Measurements on Cable Television Systems" to assist it in determining the proper test set-up, the correct test equipment properly applied, and to assist in the interpretation of test results with some suggested numerical limits for various measurements.

Competition in the home video entertainment market from various sources served to heighten the cable industry's awareness of picture quality and reliability issues. As a result, considerable attention is now being given to lightwave transmission as the technology most likely to successfully address these concerns. These events have caused the cable industry to set exacting system performance goals when implementing lightwave technology. This paper will discuss why there is a window of measurement ambiguity around the true data points that must be considered when analyzing test results from these systems.

Critical system performance measurements are generally made using a swept-tuned spectrum analyzer, either by itself or in conjunction with other test instrumentation. Some measurements, such as subcarrier ratios, can be adequately measured using a spectrum analyzer by itself. However, other performance measurements, such as carrier-to-noise and carrier-to-distortions, require more dynamic range than is possible to achieve from a spectrum analyzer alone. Bandpass filters followed by low noise preamplifiers are typically used to "enhance" the incoming signals. Although there are alternate techniques, this method is certainly the most common and is the one addressed here.

IMPACT OF SPECTRUM ANALYZER FREQUENCY RESPONSE

As with all broadband devices, spectrum analyzers have frequency response characteristics that are anything but flat. True, modern spectrum analyzers are very good, especially when sweeping small percentages of their total available bandwidth. A typical lab grade instrument might be as good as +/- 0.25 dB within any 10 MHz span while a field grade unit might be closer to +/- 0.5 dB.

Discounting the effects of all else, measuring adjacent carriers of the same power level can have this much uncertainty.

There is another less obvious problem caused by the response uncertainty of a spectrum analyzer. This occurs when we use an analyzer to "flatten" the output of a multiple frequency signal generator. This can be a good way to assess the frequency response of a device or system under test, but it may not be the best method when making critical distortion and noise performance measurements. Although the narrow-band frequency response errors of the analyzer may be small, its broadband errors can become quite large (as much as +/-1.0 dB). With this in mind, we can see that what would appear to be a flat output from the generator would actually vary across the band by the amount of the analyzer's response error. As these "analyzer-leveled" signals pass through a non-linear system under test, the harmonics generated will likewise vary accordingly. Also, these resultant distortions are not measured relative to their fundamental carriers, but are measured relative to the carrier in whose passband they fall. So, if the carrier of the channel under test was set at the -1 dB point along the analyzer's response curve while the fundamentals that created the distortions were set at the +1 dB point, then the ratio of the discrete second order product would be skewed by as much as 2 dB.

One way to minimize the effects of broadband response errors is to use a power meter to level the generator rather than a spectrum analyzer. Although this won't eliminate these errors entirely, if used carefully it can reduce these errors from several dB to perhaps a few tenths of a dB. Unfortunately, this can prove to be somewhat time consuming and we may be tempted to believe that since we're using the same analyzer "it will all come out in the wash". The dynamic ranges of active devices are not always constant across their bandwidth, and is one reason CATV active devices are measured at several places across their passband. To allow the test set to introduce this much potential error would risk compromising the tests.

EFFECTS OF AMPLITUDE MEASUREMENT INACCURACY

There can be no question that as spectrum analyzers continue to mature they become more accurate. One such improvement can be seen in their ability to measure relative power fairly accurately. However, both relative and absolute power measurements present a couple of subtle issues that, unless recognized, can cause us some problems.

Relative power accuracy is affected by a wide variety of things, but most notably analyzer flatness. As we would expect, this also has a big effect on absolute power accuracy as well. Often overlooked is the amount of calibrator error and its impact on absolute power measurements. If we think about this we can see that if an analyzer were perfect except for the calibrator error, any absolute power measurements would only be off by the amount of the calibrator error. Likewise, if the calibrator were perfect, we would only be off by the flatness error at the measured frequency. Since neither of these is in reality perfect, the amount of the error is the sum of the calibrator error and amount of the response error at the measured frequency. Depending on the frequency being measured, this can either reduce or increase absolute power error. In any case, calibrator error can increase measurement uncertainty by the amount of its error.

Fortunately, absolute power errors generally do not cause a problem since the vast majority of measurements in the CATV industry are relative. However, they can be very significant when measurements must be correlated with other instruments, or with the same instruments but at different times.

EFFECTS OF EXTERNAL BANDPASS FILTERS

External bandpass filters are used to reduce the risk of the test system adding distortions of its own into the measurements. By eliminating all but the band of interest from ever passing through active devices in the test set, the exposure to this potential error is limited.

One important characteristic of bandpass filters that we should be concerned with is their passband flatness. Depending on the type of filter used, the peak-to-valley response can be 0.5 dB, or more. Tunable filters can be much worse, especially if they are tuned at either end of their range. If, when measuring a noise or distortion ratio, the amplitude of the carrier and the amplitude of the associated noise and/or distortion is measured at the same frequency then the resultant ratio will be free from filter induced error. Furthermore, if these two data points are measured at different frequencies, then filter flatness will indeed disturb the measurement's integrity. This problem is worse with tunable filters because they tend to peak at the center of the passband and roll off on each side (see figure 1 below). This results in having the side bands suppressed by typically 0.25 dB or so. Although much less convenient, fixed filters can be characterized and their response irregularities minimized. Tunable filters are usually a single octave wide, and their passband is some percentage of the center tuning. So their useable passband may be too narrow (less than 3MHz wide) at the low end of their tuning range, while being too wide (greater than 5MHz) at the high end of their range.

IMPEDANCE RELATED PROBLEMS

As frustrating as it can be, we in the CATV industry must endure a 75 ohm life in a 50 ohm world. We are forced to measure a broad spectrum in very narrow portions that introduces additional sources of errors due to interconnecting cables, multiple impedance mismatches and transformations, etc. All these factors introduce response uncertainties of their own making the job of calibrating them out virtually impossible.

Thankfully, many analyzers are now available with 75 ohm inputs and with the amplitude scale calibrated in dBmV. Other instruments come with one 50 ohm input and one 75 but typically have only a 50 ohm calibrator. Additionally, digital analyzers generally have the capability of displaying amplitude data in a multitude of scales, including dBm and dBmV, but a word of caution is in order. It is not uncommon for these scales to be referenced to 50 ohms, which can offset the dBmV scale by 10*log(75/50), or 1.76 dB. This can be particularly tricky when using one of those analyzers that has both inputs and you switch

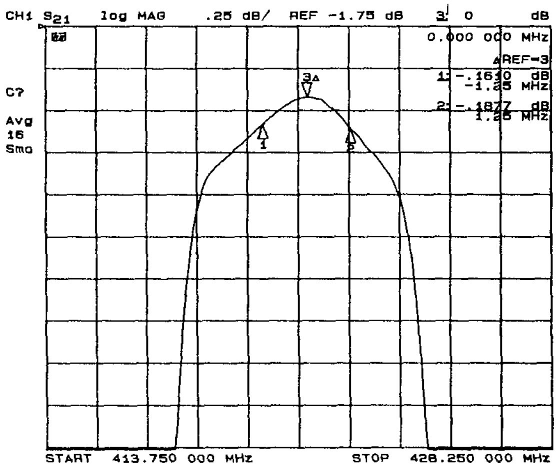

Figure 1
Typical Tunable Bandpass Filter
Response Characteristics

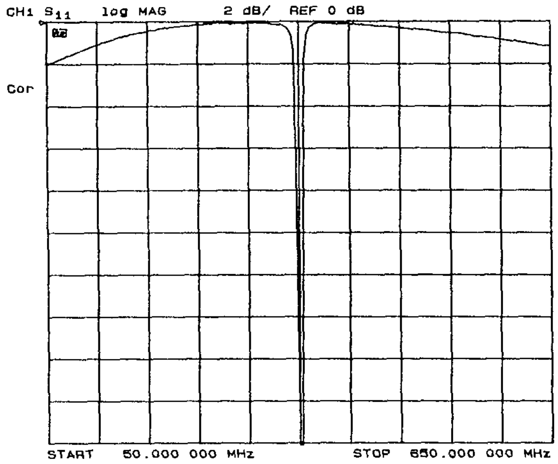

Figure 2
Typical Tunable Bandpass Filter
Return Loss Response

between the two. A simple check for this is to set the reference level to 0 dBm, then switch the scale to read out in dBmV. If it says 48.75, you're all set; if it says 47, you'll know to adjust for it.

Bandpass filters are pretty close to open circuits out of band. In fact, 1 to 2 dB of return loss can be considered optimistic (see figure 2 above). While some devices under test may not be affected too badly by this, others may not be unconditionally stable. In these cases, poor terminations can cause unexpected results. Simply using a 10 dB pad as the terminating load for our device under test can go a long way in preventing this from becoming too much of a problem.

AUTOMATED MEASUREMENTS

In recent years highly programmable instruments have become commonplace. Test setups can be stored quickly in memory, trace data routed to memory cards, and even entire measurement sequences can be recalled and executed at the touch of a button. This is an extremely effective way to perform difficult measurement sequences with precision. By reducing the opportunities for the operator to make procedural or computational errors, we achieve a level of consistency and repeatability unheard of just a few years ago. In fact great strides have been made in standardizing automated testing methods based on the recommended practices for manual testing, further enhancing repeatability and correlation.

Although automated measurements can and should be used for all these reasons, there are a few things that should be kept in mind. First, digitally based instruments are well known for their high degree of numerical resolution. Unfortunately, this is often confused with accuracy. Simply because an instrument reads out in hundredth's of a dB does not mean that it's accurate to within a hundredth of a dB.

Another area of caution with automated measurements concerns dynamic range. A spectrum analyzer's dynamic range can be thought of as the amount of the CRT display for which the instrument's specifications hold true. Unfortunately, this is generally less than the total amount of display range we have available. Usually, dynamic range runs from 50-70 dB, while display range is normally 80-100 dB. This means that if we measure ratios directly from the CRT display that are greater than the dynamic range, our measurements can have fairly significant errors. Also, many instruments are prone to log scale fidelity errors and these can add up quickly. This can account for as much as 1.0 dB of error even when measuring inside the instrument's dynamic range window. Several instruments available today no longer suffer from significant log amp anomalies but these tend to have less dynamic range. These problems can be minimized by ensuring all signals and noise measurements are made within the first two graticule divisions.

Special care should be excercised when adjusting tunable filters. When set toward the low end of their ranges, they tend to get quite narrow. It may not be immediately apparent but the edges of the measurement band may become overly attenuated by the filter's skirts. Certain software routines for measuring carrier-to-noise ratios will search the entire display for the minimum amount of noise, and in these cases can be off by several dB. This issue is addressed in some software designs by always measuring noise at a fixed location near the carrier, while still others limit the allowable frequency excursion when searching for minimum noise.

Automating measurements offers many advantages to manual systems. Enhanced repeatability, as well as freedom from such things as operator and computational errors, etc., are compelling reasons to use this technology. Although digitally based instruments can sometimes software-correct repeatable errors that occur in hardware, they cannot improve a test system's base accuracy. In other words, if an instrument has an absolute power measurement uncertainty of 1 dB, all measurements made by that system will have at least that much uncertainty, whether a human is physically pushing buttons or a computer is doing it electronically.

Low Noise Preamplifiers

Finally, a note when using a low noise preamplifier for signal enhancement. Though it is sometimes overlooked, preamplifiers do add noise to the measurement system. Although this isn't always a problem, it can cause misleading results when a high degree of test system sensitivity is required. The exact amount of noise added to the system depends on both the noise figure of the analyzer and the noise figure of the preamplifier. Figure 3 shows the amount of noise added to a lab grade analyzer with 0 dB of input attenuation. The noise figure of this particular amplifier is approximately 4 dB. This is especially true when trying to measure very small amounts of noise and distortion. Therefore, whenever determining sensitivity, always terminate the input to the test system (typically the input to the bandpass filter) rather than the input of the spectrum analyzer.

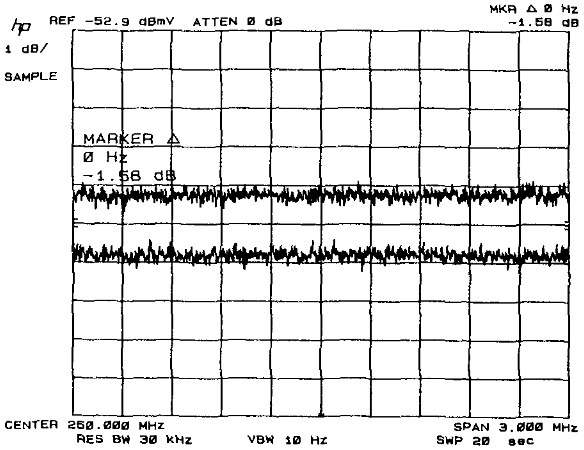

Figure 3
Test System Sensitivity with and without
Low Noise Preamplifier

CONCLUSIONS

Our observations were based on many measurements made using a wide variety of makes and models of test equipment. The cautions suggested were not meant to discourage anyone from making measurements, but simply to point out that all measurements include uncertainties inherent in the process. By understanding some of the sources of these uncertainties, anyone making measurements on broadband AM-VSB systems can minimize their effects.

When making critical distortion and noise measurements, careful use of a broadband power meter can minimize the uncertainties caused by unleveled multi-frequency signal sources. Where applicable, the use of fixed-tuned bandpass filters with known characteristics can reduce the effects of the filter's passband ripple.

While automated techniques aid in making repeatable measurements, they do suffer from the limitations discussed above. Therefore, the test system operator must carefully monitor the process to ensure that the data is taken without exceeding the limitations of the test instruments.

This paper was not intended to be an all-inclusive treatment of measurement inaccuracies but to sensitize the industry to their existence. As test instruments and test methods improve, these anomalies will become smaller. As a result of ongoing efforts in our labs, we intend to present for future consideration a few specific test practices that may help narrow this window of uncertainty. For the time being, however, it appears that even with the best efforts applied, the window of uncertainty in these types of measurements is roughly 2 dB, and is independent of the test methodology used. Unfortunately, we are all subject to this degree of uncertainty so it is important that we maintain a proper perspective toward our test data.